SELF-BIASED FOLDED CASCODE INSTRUMENTATION AMPLIFIER USING CHOPPER TECHNIQUE FOR ECG

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SELF-BIASED FOLDED CASCODE INSTRUMENTATION AMPLIFIER USING CHOPPER TECHNIQUE FOR ECG

by

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LIST OF ABBREVIATIONS AND SYMBOLS

ECG or EKG	Electrocardiogram
HRV	Heart rate variability
SNR	Signal to noise ratio
IA	Instrumentation amplifier
ADC	Analog-to-digital converter
CMOS	Complementary metal oxide semiconductor
3OA	Three operational amplifier
$1/f$	Flicker noise
CMRR	Common mode rejection ratio
AC	Alternating current
DC	Direct current
CBIA	Current balance instrumentation amplifier
DDA	Differential difference amplifier
OTA	Operational transconductance
ACCIA	AC coupled chopper stabilized instrumentation amplifier
EEG	Electroencephalogram
PSRR	Power supply rejection ratio
MOS	Metal oxide semiconductor
LPF	Low pass filter
BPF	Band pass filter
NMOS	Negative-channel MOS
PMOS	Positive-channel MOS

V_{ds}	Drain to source voltage
$V_{ds,sat}$	Drain to source voltage in saturation region
f_c	Chopper frequency
g_m	Transconductance
r_{ds}	Drain to source small signal resistance
v_{out}	Output voltage
I_D	Drain current
μC_{ox}	Parameter *k'*
λ	Channel length modulation
V_{T0}	Threshold voltage
L	Length
W	Width
V_{GS}	Gate to source voltage
V_{DD}	Voltage supply
A_V	Voltage gain
C_L	Load capacitor
C_H	Capacitor of high pass filter
R_H	Resistor of high pass filter
UGBW	Unity gain bandwidth
MOSFET	Metal oxide semiconductor field effect transistor
t_{ox}	Oxide thickness
TT	Typical NMOS typical PMOS
FF	Fast NMOS fast PMOS

SS	Slow NMOS slow PMOS
FS	Fast NMOS slow PMOS
SF	Slow NMOS fast PMOS
ϕ	Phi
DRC	Design Rule Checker
f_L	Low cut-off frequency
f_H	High cut-off frequency
f_0	Center frequency
DFT	Discrete Fourier Transform
PSS	Periodic Steady State
SiO_2	Silicone oxide
K_f	Flicker noise coefficient
C_{ox}	Gate oxide capacitance per unit area
k	Boltzmann's constant
T	Temperature
Δf or BW	Bandwidth
NEF	Noise efficiency factor
$V_{in,rms}$	Total equivalent input noise
I_{total}	Total current
$V_{in,peak}$	Peak voltage input signal
$V_{out,peak}$	Peak voltage output signal

PENGUAT PERALATAN KASKOD TERLIPAT PINCANG-KENDIRI MENGGUNAKAN TEKNIK PEMENGGAL UNTUK EKG

ABSTRAK

Abad kedua puluh satu telah menyaksikan pertumbuhan teknologi bagi aplikasi rakaman bioperubatan terutamanya sistem rakaman elektrokardiogram (EKG) dan mempunyai kesan yang mendalam kepada kehidupan harian kita. Sistem rakaman EKG lazim yang terlalu besar lalu mengehadkan masa perolehan telah membawa kepada rekabentuk peranti EKG mudah alih terkendali bateri kuasa rendah. Ia membantu untuk memastikan kemudahalihan yang baik dan meningkatkan kemudahgerakan, membebaskan pesakit daripada wayar yang memberi kegusaran dan ketidakselesaan. Selain itu, hingar kerlipan (1/*f*) yang berkekerapan rendah menjadi halangan yang paling besar bagi peranti EKG yang boleh diharap, memandangkan isyarat EKG mempunyai ciri-ciri yang beramplitud rendah dan juga berkekerapan rendah. Oleh sebab itu, matlamat kajian ini adalah untuk merekabentuk sebuah penguat kebezaan bahagian depan kuasa rendah sebagai peranti pemantauan EKG dan mencapai penguat dengan hingar dirujuk masukan yang rendah khususnya hingar kerlipan berkekerapan rendah. Litar ini adalah berdasarkan teknik pemenggal yang dilaksanakan bersama struktur kaskod terlipat pincang-kendiri dengan penggunaan kuasa yang lebih rendah daripada pendekatan sebelumnya tanpa menjejaskan prestasi. Skim pincang-kendiri yang menjimatkan kuasa dan mengurangkan keluasan litar telah dipilih untuk menghapuskan keperluan litar pincangan luar dengan menjana voltan pincang dari nod dalaman litar. Ia terbentuk melalui satu siri pelarasan berlelar nilai komponen dan saiz transistor. Bagi kes pelaksanaan pemenggal, teknik pemodulatan menukarkan isyarat masukan dengan julat kekerapan rendah kepada julat kekerapan yang lebih tinggi daripada hingar kerlipan perusa. Modul pemenggal yang kedua pula bertindak sebagai penyahmodulat yang membawa keluaran yang dikehendaki kembali ke jalur dasar dan mengubahkan hingar kepada kekerapan pemenggal yang berkekerapan tinggi. Hingar termodulat dan pepaku terpenggal yang tidak diingini juga disinggirkan oleh satu penapis lulus jalur yang berkekerapan rendah. Dengan menggunakan cara yang sama, penguat kaskod terlipat telah dimanfaatkan dalam hingar rendah disebabkan saiz peranti yang lebih kecil memberikan nisbah isyarat hingar yang baik kerana keluasan mutlak bagi rekabentuk tersebut menyumbangkan hingar. Litar ini direka menggunakan pemprosesan teknologi SILTERRA 0.18 µm CMOS dengan VIRTUOSO CADENCE. Keputusan simulasi pra-bentangan bagi penguat yang tersebut telah menunjukkan kuasa yang amat rendah, iaitu 1.926 µW serta hingaran rendah, iaitu 415 nV/ √ Hz pada 10 Hz, telah mengatasi prestasi seni bina penguat bioperubatan yang terkenal. Tambahan pula, gandaan kebezaan voltan yang tinggi, iaitu 54.32 dB dan 102.82 dB dalam nisbah penolakan ragam sepunya tercapai.

SELF-BIASED FOLDED CASCODE INSTRUMENTATION AMPLIFIER USING CHOPPER TECHNIQUE FOR ECG

ABSTRACT

In twenty-first century, it has been witness the tremendous growth of technology in biomedical recording application particularly electrocardiogram (ECG) recording system and has had a profound impact on our daily life. The conventional ECG monitoring systems that are too bulky in nature which restrict the acquisition time has led to the design of low power battery operated portable ECG device. It helps to ensure good portability and enhanced mobility, freeing the patient from entanglement of wires which conceives annoyance and discomfort. In addition, the low frequency flicker noise (1/*f*) has been the biggest hindrance for reliable ECG monitoring application device since ECG signals have the characteristics of low amplitude and low frequency. Therefore, the goals of this work are to design a low power front end differential instrumentation amplifier for ECG monitoring device and to achieve low input referred noise of the amplifier specifically low frequency flicker noise. The circuit is based on the chopper technique which is implemented together with self-biased folded cascode structure that has significant lower power consumption than the predecessor's approaches while keeping the performance unchanged. A self-biased scheme that saves power and reduces circuit area is chosen to eliminate the needs of external biasing circuitry by generating bias voltages from internal nodes of the circuit. It is developed through a series of iterative adjustments of component values and transistor sizes. For the case of chopper implementation, the used modulation technique converts the low frequency range of the input signals to a higher frequency range far above the dominant flicker noise. The second chopping module that acts as a demodulator brings the desired output back to the baseband and shifts the noise to the high chopping frequency. The modulated noise and the unwanted chopping spikes are then removed by a low frequency band pass filter. By the same token, folded cascode amplifier has benefit in low noise since smaller device size results in a better signal to noise ratio as the absolute area of the design contribute noises. The circuit is designed using SILTERRA 0.18 μm CMOS technology process with VIRTUOSO CADENCE. The pre-layout simulated results of the amplifier show ultra-low power of 1.926 μW and low noise of 415 $nV/\sqrt{Hz}$ at 10 Hz which outperforms the renowned architectures of biomedical amplifier. Moreover, high differential voltage gain of 54.32 dB and 102.82 dB in CMRR are achieved.

CHAPTER 1

INTRODUCTION

1.1 Project Overview and Motivation

The heart is one of the most crucial organs in the human body. In order to keep the organs working, the heart functions as a pump to circulate oxygen and blood that carries nutrient throughout the body which shown in Figure 1.1. The flowing blood withdraws waste products produced from the body to the kidneys (Chong et al., 2006).

The heart is comprised of four chambers, two atriums and two ventricles. The right atrium takes in blood from the entire body returning to the heart. The blood flows through the right ventricle and is pumped to the lungs where it is oxygenated and passed back to the heart through the left atrium. Then, the blood flows through the left ventricle and is pumped again to be scattered to the whole body via the arteries (Casillas et al., 2010).

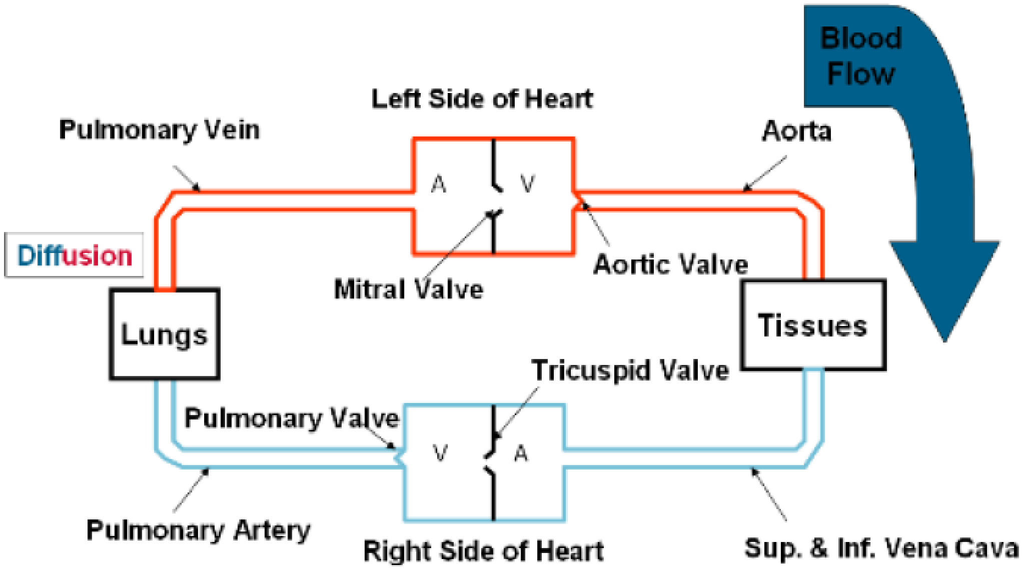

Figure 1.1: Blood circulation scheme (Casillas et al., 2010)

An electrocardiogram (ECG), also known as EKG, is a graphical trace of the voltage produced by cardiac or heart muscle during a heartbeat. It indicates the performance of the heart precisely and accurately whereby the rate of the heartbeat generated by the heart is proportional to the amount of effort being exerted by body.

The heart shows a pumping characteristic as the electrochemical impulses that spreads out in the heart cause the cells to contract and relax in an orderly time when the heart is beating. Heartbeat can be measured at the surface of the body as the body is conductive with fluid content and this electrochemical action is electrical in nature. Figure 1.2 reveals distinctive upward and downward deflections that reflect the alternate contraction of the atria and the ventricles of the heart. An approximately 1 mV voltage potential originates between several body locations.

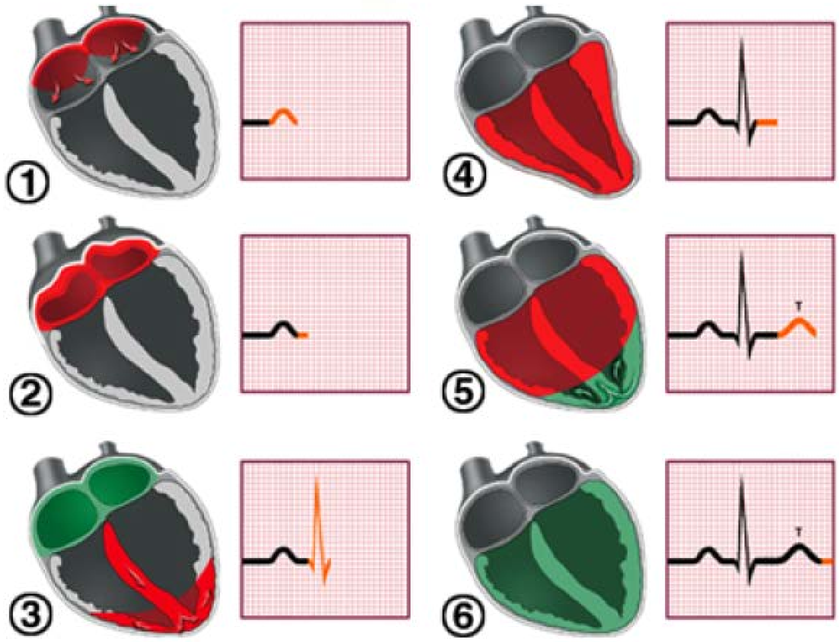

Figure 1.2: Myocardium electrical activity (Casillas et al., 2010)

A sample trace of a typical ECG output for a single cardiac cycle waveform of a normal heartbeat is shown in Figure 1.3. There are commonly five identifiable points in an ECG trace which denoted by letters P, Q, R, S, and T. Atria depolarization, P is due to the action of atria contraction also known as atria complex whereas the rest are all due to polarization and depolarization of ventricles and are known as ventricular complexes (Raju, 2007). The cardiac cycle waveform that varies in time between the R's which are the peaks of a heartbeat, is called heart rate variability (HRV). ECG that measures HRV plays a vital role in predicting a variety of diseases such as heart attack, diabetes and patients who have suffered from cardiac failure as they are shown with reduced HRV.

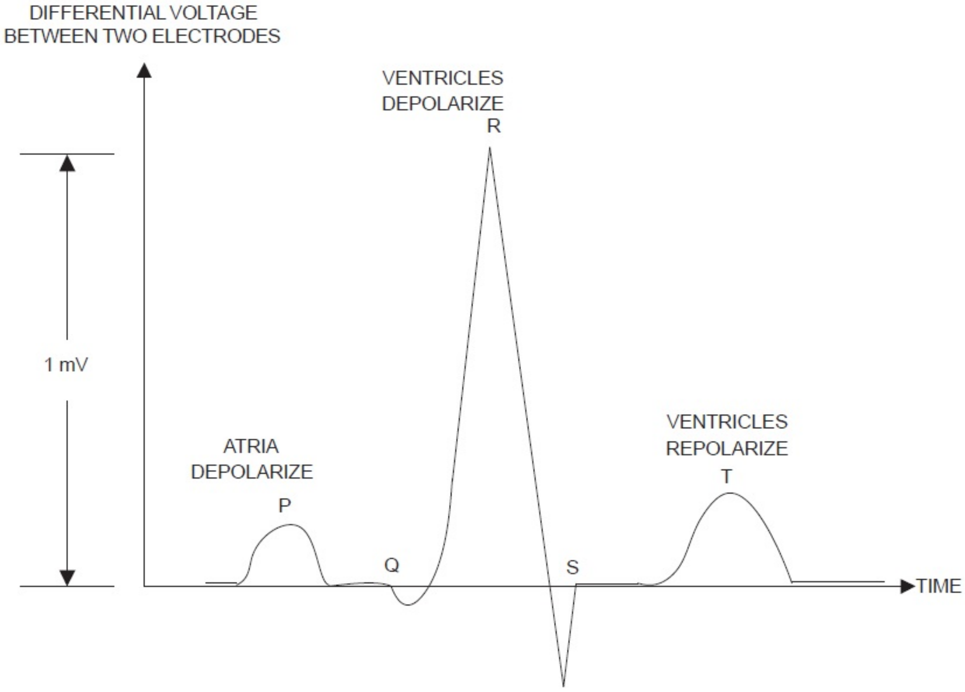

Figure 1.3: ECG waveform of a single cardiac cycle (Raju, 2007)

In recent years, portable biomedical instrumentation has becoming a growing trend in patient diagnosis and treatment due to the reason that the conventional biomedical monitoring systems are too bulky in nature and time consuming. Portable ECG monitoring devices ensure good portability and enhanced mobility, freeing the patient from entanglement of wires. The advanced technology has led to the design of low power consumption battery operated portable medical instruments particularly in ECG device whereby continuous monitoring helps to improve patients' quality of life, identify cardiac diseases and reduce hospitalization.

Figure 1.4 depicts the block diagram of the ECG monitoring system where it consists of heartbeat signal, electrodes, a front end instrumentation amplifier (IA), data acquisition or analog-to-digital converter (ADC), and transmitter. Electrodes receive heartbeat signal from patients' chest and then send them through an instrumentation amplifier for amplification. Due to the very small voltage ECG signal amplitudes of less than 1 mV, the instrumentation amplifier has to provide a high yet stable AC gain. Next, the amplified signal will be digitized by ADC in data acquisition part where it converts analog waveforms into digital values for processing before transmitting them to receiver module for display (Fuhrhop et al., 2009, Yama et al., 2007, Rehman et al., 2012).

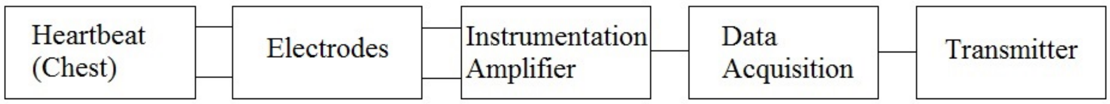

Figure 1.4: Block diagram of the ECG monitoring system

1.2 Problem Statement

Biomedical waves are typical bio-potential signals that are recorded regularly in modern clinical practice. Generally, patients are attached to a cumbersome and high-powered biomedical instruments which conceives annoyance, discomfort, and weaken their mobility. This restricts the acquisition time, rules out the continuous monitoring of patients, and disturb the diagnosis of the illness.

Portable monitoring and management requires the development of smart biomedical monitoring systems with stringent size and power autonomy constraint. Hence, there is a growing demand for low power, smaller size and ambulatory bio-